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On the Optimum DS-CDMA Channel Bandwidth for Personal Communication Systems

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Abstract

With the development of both narrowband and wideband DS-CDMA systems there has been much interest in establishing the optimum spread spectrum bandwidth. Previous publications by the authors have indicated the importance of the bandwidth allocation in determining the DS-CDMA system's ability to exploit the temporally dispersive effects of the mobile radio channel. This paper discusses some of the issues concerning the optimum spread spectrum bandwidth for use in proposed 3rd generation systems, such as the European Universal Mobile Telecommunications System (UMTS), based upon recent system-specific wideband channel sounding measurements in the City of Bristol combined with results from computer simulation of a RAKE receiver architecture.

1 Introduction

The DS-CDMA system developed by Qualcomm [1] has a chipping rate of 1.23 MHz and was designed for operation in service areas with quite large RMS delay spreads. Wideband channel sounding measurements in the UK have indicated smaller RMS delay spreads than those present in equivalent operational environments in the US, due to differences in the scattering volume. Consequently, this spreading bandwidth would be insufficient to provide a significant degree of path diversity. At the other extreme, the system proposed by SCS Mobilecom Inc. [2] has a chipping rate of 23 MHz, which would be able to deal with a wider range of mobile radio channel characteristics but with a corresponding increase in system cost and complexity.

This contribution aims to develop understanding of

the effects of altering the chipping rate and hence provide further recommendations for the optimum channel bandwidth for DS-CDMA mobile radio systems, when deployed to meet the needs of 3rd generation systems.

2 Internal Diversity

The wideband mobile radio channel response can be represented by multiple impulses having real positive amplitudes (β_k), propagation delays (τ_k) and associated phase shifts (θ_k), where k is the path index and theoretically extends from 0 to ∞ . Thus the complex lowpass impulse response is given by :

$$h(t) = \sum_k \exp(j\theta_k) \delta(t - \tau_k) \quad (1)$$

A key feature of DS-CDMA systems is their inherent ability to distinguish multipath signals as a result of the wideband nature of the spread spectrum signal when compared with the delay spread of the channel. The temporal resolution of the spread spectrum signal is given by :

$$T_c = \frac{1}{W_{ss}} \quad (2)$$

where T_c is the chip duration and W_{ss} is the chipping rate. Thus the maximum number of multipath components, L , that can be resolved by the receiver is given by the following relation :

$$L \leq \frac{T_m}{T_c} + 1 \quad (3)$$

where T_m is the total multipath delay spread of the channel.

Where a synchronisation technique employing a Delay Locked Loop (DLL) (or similar technique) has been

used to recover incoming signal and a locally generated copy of the spreading code is available, the common RAKE receiver architecture (shown in Figure 1) is used. This is a pre-detection diversity combining architecture and thus requires co-phasing of the individual diversity signals. Its functionality can be increased further by using programmable delay blocks allowing tracking of more distant, but strong, multipath components.

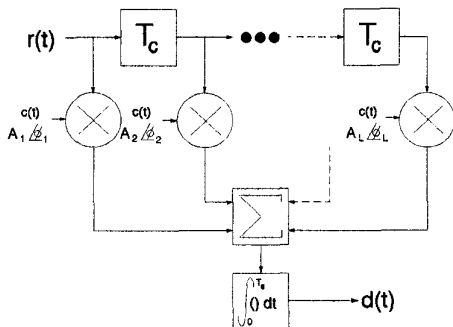


Figure 1: RAKE Receiver Architecture

If a digital matched filter is used to perform the secondary demodulation then a different architecture needs to be used, since a local copy of the spreading code is not directly available. A correlation threshold within the matched filter needs to be specified to produce a timing pulse for the master demodulator, this can then be delayed and passed to slave demodulators allowing processing of other multipath signals. This post-detection diversity combining architecture does not require that the individual diversity signals be co-phased.

Whichever technique is chosen, in order to fully appreciate the benefits of using internal diversity in the form of a RAKE receiver it is necessary to have a system-specific understanding of the mobile radio channel.

To determine the signal fading characteristics of all diversity signals for any given chipping rate it is necessary to have complete knowledge of all rays arriving at the receiver's antenna; that is amplitude, phase, excess time-delay and arrival angle. Since this could require an infinite chipping rate it is a simpler task to perform system-specific channel sounding measurements. The measurements presented in this paper were taken using the programmable channel sounder described in [3]. A large number of cross-correlations were recorded for each chipping rate and these were then fed into a RAKE receiver simulation package.

3 Results

Typical cross-correlation channel responses are shown in Figures 2 and 3. These diagrams illustrate two important points about the effect of altering the chipping rate; the signal variability of the first diversity signal reduces with higher chipping rates, while the amount of multipath activity in the other diversity branches increases. This is discussed in greater detail in [4].

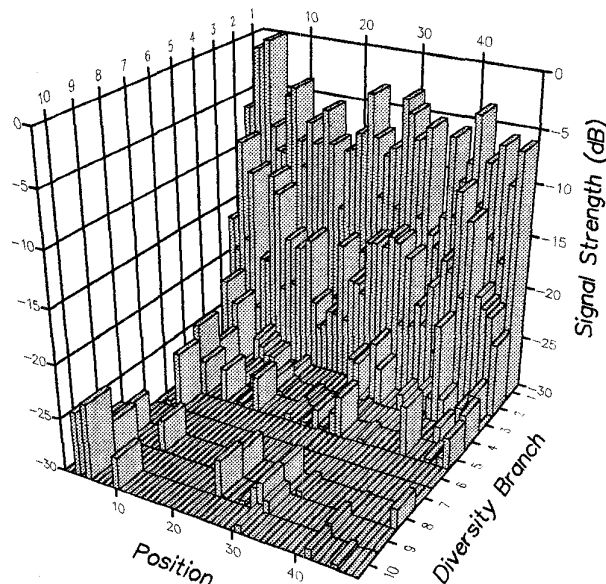


Figure 2: Wideband Channel Response at 1.25 MHz

After equal-gain post-detection combining of the multipath signals, the results shown in Figures 4 and 5 were obtained. Note that generally as the diversity order increases, the contribution in terms of SNR reduces and accordingly these results represent an optimistic view of the improvement in signal quality. However, what is important are the trends as the chipping rate is varied. In Figure 4 note that there is little difference between the chipping rates for 1.25 MHz, 2.5 MHz and 5.0 MHz.

For comparison with standard narrowband statistics the coefficient of variation [5] is used, which for the Rayleigh distribution is given by :

$$\sigma_n(dB) = 20 \log_{10} \sqrt{\frac{2 - (\pi/2)}{\pi/2}} = -2.82 \text{ dB} \quad (4)$$

In Figure 5 with a single diversity signal at 1.25 MHz there is no noticeable reduction in the signal variability when compared with the value derived for the Rayleigh probability density function in equation 4.

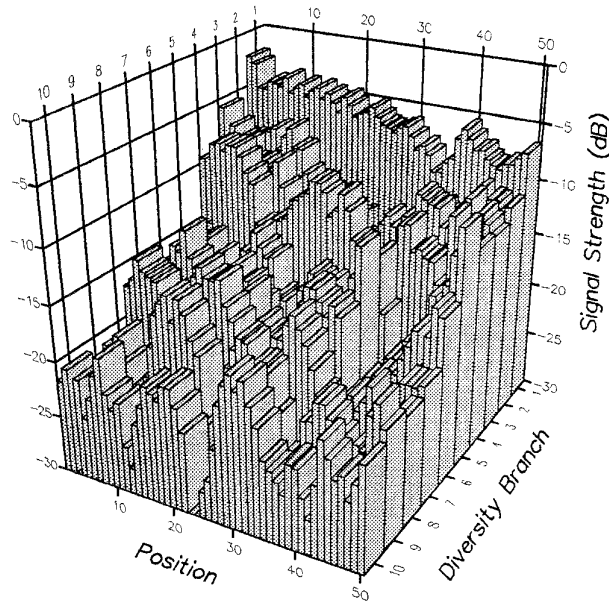


Figure 3: Wideband Channel Response at 20.0 MHz

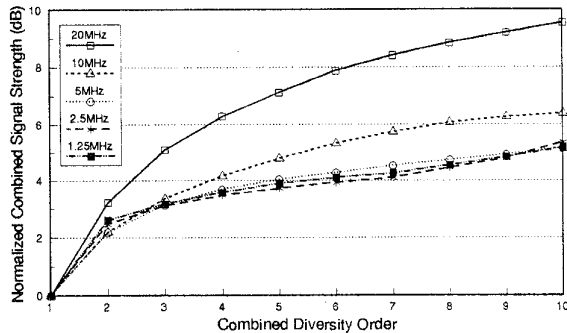


Figure 4: Normalized Mean Signal Strength versus Diversity Order

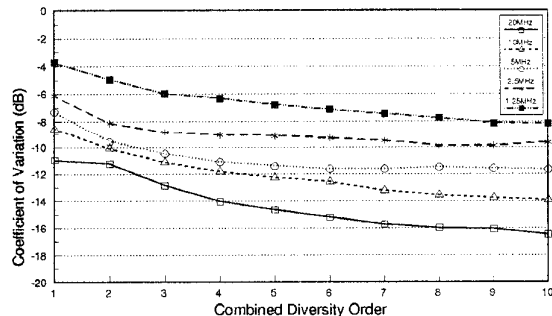


Figure 5: Coefficient of Variation of Combined Signal Strength versus Diversity Order

4 Conclusions

For the environments considered to date, with DS-CDMA systems less than 10 MHz, there is little advantage (in terms of signal strength) in employing greater than second-order internal diversity. Conversely, due to the high stability of the first diversity signal at high chipping rates there is little advantage, in terms of signal stability, in processing high orders of internal diversity signals.

It would appear that there is little benefit in using chipping rates much beyond 20 MHz to flatten the fast-fading characteristics (although further measurements are required to confirm this). The exception to this is of course with co-existence applications, where high processing gain is required to mitigate the effects of narrowband interference [2].

5 Future Work

5.1 Wideband Channel Model

Many of the observed effects noted in this paper and in [4] can be explained using the following wideband channel model. The development of such a model is essential to enhance current understanding of wideband propagation for DS-CDMA applications. Results will be presented in future publications comparing simulation and actual measurements.

From the complex lowpass impulse response given by Equation 1, the Saleh [6] model is derived. Although this model was originally intended to model the indoor multipath environment, it is equally applicable to outdoor multipath propagation models after suitable modification.

The model assumes that rays arrive in clusters (evident from studies of typical urban radio channel impulse responses, such as the one shown in Figure 6 taken using a wideband correlation sounder in the City of Bristol). The arrival times of the first rays of the clusters are modeled as a Poisson arrival process with a fixed rate Λ . Within each cluster, subsequent rays also arrive according to a Poisson arrival process with a fixed rate λ . Typically, each cluster consists of many rays, *i.e.*, $\lambda \gg \Lambda$. Thus the process can be described by the following two independent inter-arrival exponential probability functions

$$p(T_l|T_{l-1}) = \Lambda \exp[-\Lambda(T_l - T_{l-1})] \quad l > 0 \quad (5)$$

$$p(\tau_{kl}|\tau_{(k-1)l}) = \lambda \exp[-\lambda(\tau_{kl} - \tau_{(k-1)l})] \quad k > 0 \quad (6)$$

For the purposes of computer simulation the arrival

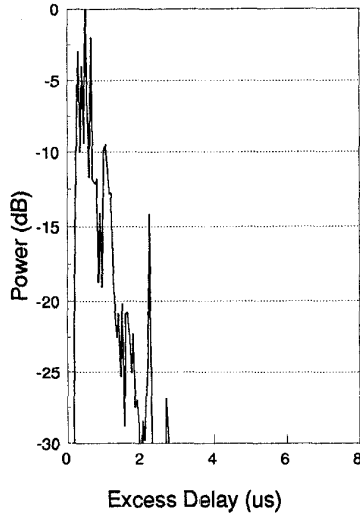


Figure 6: Typical Urban Channel Impulse Response

times can be generated using the following transformations :

$$T_l - T_{l-1} = -\frac{1}{\Lambda} \ln(\text{RND}(1)) \quad (7)$$

$$\tau_{kl} - \tau_{k(l-1)} = -\frac{1}{\lambda} \ln(\text{RND}(1)) \quad (8)$$

where $\text{RND}(1)$ is a standard computer-generated uniform probability distribution over $[0, 1]$.

Thus, the generated complex lowpass impulse response is given by :

$$h(t) = \sum_{l=0}^{\infty} \sum_{k=0}^{\infty} \beta_{kl} \exp[j\theta_{kl}] \delta(t - T_l - \tau_{kl}) \quad (9)$$

The first diversity signal contains a portion of the first cluster of rays and clearly, with increasing signal resolution, will become more deterministic. Additional diversity signals will not necessarily be synchronized to the start of a cluster and will therefore have less predictable characteristics. Signal strengths for the individual diversity signals will be dictated by the inter-cluster and intra-cluster decay rates.

This channel model thus allows the designer to specify the impulse response and predict the effect of altering the chipping rate of the system and thus determine the optimum spreading bandwidth.

5.2 DS-CDMA Testbed

Results will shortly be presented from a DS-CDMA Testbed, developed at Bristol, which assesses system performance in terms of BER for a single user link with various chipping rates and different orders of diversity.

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